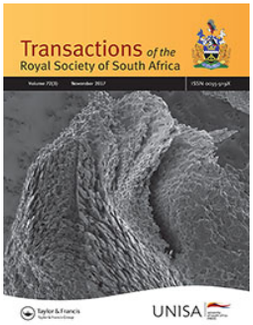

Transactions of the Royal Society of South Africa

ISSN: 0035-919X (Print) 2154-0098 (Online) Journal homepage: http://www.tandfonline.com/loi/ttrs20

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To cite this article: Jacques van Rensburg, Brian W. van Wilgen & David M. Richardson (2017) The challenges of managing invasive alien plants on private land in the Cape Floristic Region: insights from Vergelegen Wine Estate (2004–2015), Transactions of the Royal Society of South Africa, 72:3, 207-216, DOI: 10.1080/0035919X.2017.1288175

To link to this article: https://doi.org/10.1080/0035919X.2017.1288175

Transactions of the Royal Society of South Africa, 2017
Vol. 72, No. 3, 207–216, https://doi.org/10.1080/0035919X.2017.1288175

The challenges of managing invasive alien plants on private land in the Cape Floristic Region: insights from Vergelegen Wine Estate (2004–2015)

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Alien plant invasions are a major threat to biodiversity and ecosystem functioning in South Africa's Cape Floristic Region (CFR). Large-scale government-funded management initiatives are underway to reduce the extent of invasions in this region. Among the many challenges are the huge spatial extent of the invasions and difficulties in coordinating management efforts across large areas of invaded land in private ownership. Very little information is available on the success of privately-funded alien plant control initiatives. This study investigated the effectiveness of one large project in reducing alien plant cover, the challenges faced and the costs associated with long-term clearing operations on privately-owned land in the CFR. Results for the study area (Vergelegen) show that the cover of dense invasive plant stands declined by 70% over 10 years since management operations began, but that operations cost 3.6 times more than was originally estimated (ZAR 43.6 vs 12.19 million, respectively). The challenges associated with managing invasive alien plants (IAPs) on private land are very similar to those faced on state-owned land, with the efficiency of management being constrained by multiple interacting environmental and socio-economic factors. However some success in managing IAPs can be achieved by adhering to basic principles, including careful planning with clear achievable goals in mind, a commitment to stable long-term funding and regular monitoring. Most private land owners cannot afford the substantial investment of resources that would be required to clear large stands of IAPs and to ensure that cleared areas are maintained to prevent re-invasion, and finding ways to fund this remains a challenge.

Keywords: biological invasions; fynbos; invasive species; management; tree invasions

INTRODUCTION

Invasive alien plants (IAPs) pose a significant threat to the biodiversity and functioning in many of the world's ecosystems (Mack *et al.*, 2000; Pimentel *et al.*, 2005). Many alien plant species, including many species of trees and shrubs, have invaded South African ecosystems (Richardson *et al.*, 1997; Henderson 2007; Kotzé *et al.*, 2010). Some of these plants reduce scarce water supplies and negatively affect biodiversity and the functioning of ecosystems (Le Maitre *et al.*, 2000; van Wilgen *et al.*, 2008). Millions of Rand have been spent on preventing and mitigating the impacts of these invasions (van Wilgen *et al.*, 2012).

The government-funded programme 'Working for Water' (WfW) was launched in 1995 to address this problem. It is the largest conservation project in Africa (van Wilgen, 2009) and the world's most ambitious programme for managing IAPs (Koenig, 2009). Despite important advances, a major obstacle faced by WfW is the complex interactions among factors that influence the dynamics of the invasive species and the interplay with a wide range of socio-political issues. This is especially challenging in the fire-prone fynbos vegetation of the Cape Floristic Region (CFR) (Roura-Pascual *et al.*, 2009; van Wilgen *et al.*, 2016b). The CFR is subjected to many external pressures (e.g. urbanisation, land-use change and climate change) that threaten the long-term persistence of its biological diversity (van Wilgen *et al.*, 2016). The remaining natural habitats are threatened by the expansion of woody IAPs (Rouget *et al.*, 2003; Latimer *et al.*, 2004). Despite the large investment of resources, it is unclear whether the extensive control operations are substantially reducing the problem and alleviating the threats to the region's biodiversity (van Wilgen *et al.*, 2016b).

A large percentage of invaded land in the CFR is privately owned. In 2008 WfW took a policy decision to phase out management interventions on private land, and to instead use incentives and disincentives to encourage private landowners to manage IAPs on their property themselves. WfW contributes to labour costs incurred by private landowners as an incentive, and as a disincentive the government can impose penalties on landowners if they fail to comply with legal requirements to control IAPs. Many landowners support the idea of inclusive environmental governance involving public and private sectors and private land-owners, but few landowners have the expertise and resources to deal with widespread dense stands of invasive trees and shrubs. There is an urgent need for monetary incentives, motivational tools and

Published online 10 Mar 2017

regulatory enforcement if the desired outcomes are to be achieved (Urgenson, 2011).

We know of no thoroughly documented accounts of large-scale, privately-funded initiatives to control IAPs in the CFR or elsewhere. An evaluation of case studies is needed to identify and elucidate the particular challenges faced by private landowners, and to derive lessons that could help other private landowners to address the management of IAPs more effectively. This paper evaluates one such project – probably the most ambitious and expensive IAP management effort ever undertaken on private land in South Africa. The case study involves the alien plant operations at Vergelegen Wine Estate (hereafter Vergelegen) in Somerset West, in the Western Cape Province. In 2004, when the programme was initiated, 70% of the natural and semi-natural vegetation at Vergelegen (total area: 3200 ha) was heavily invaded by alien trees and shrubs. As with all alien plant control operations, efforts at Vergelegen have faced many challenges. These have included dealing with wildfires, invasion from surrounding land, re-invasion following control, logistical issues relating to biomass removal, and financial uncertainty and constraints. This paper sets out to document the cost, extent and effectiveness of this operation and to identify the factors that affected progress towards the goal of reducing the cover of IAPs.

METHODS

Study area

Vergelegen Wines (Pty) Ltd. (3200 ha in extent) (Figure 1) is located in the Hottentots Holland mountain range near the town of Somerset West in the Western Cape Province of South Africa. The area falls within the Lourens River Protected Natural Environment and is privately-owned. It is subjected to a Mediterranean-type climate with a mean annual rainfall of 750 mm, 46% of which falls in the winter months of June to August. Altitude ranges from 70 to 1020 m a.m.s.l (above mean sea level). About a third of the study area has been converted to crop agriculture (mainly vineyards), while the rest has remained as natural vegetation of three main types: Boland granite fynbos, shale renosterveld and Lourensford alluvium fynbos (Mucina *et al.*, 2014).

The remaining natural vegetation has been invaded by alien trees and shrubs; dense stands of invasive plants now cover about two thirds of the area. The most widespread invaders are pines (*Pinus pinaster* Aiton and *P. radiata* D. Don), wattles (mainly *Acacia mearnsii* De Wild), hakeas (*Hakea sericea* Schrad. & J.C. Wendl.) and eucalypts (*Eucalyptus cladocalyx* F. Muell.). The wattles and eucalypts are largely confined to lower-elevation areas close to streams or drainage lines, whereas most of the pine invasions occur on higher-elevation slopes (Figure 2). The earliest invasive stands were located around the Vergelegen homestead and in transformed areas (agricultural land and plantations), and these spread across the natural vegetation over time. Poorly-managed agricultural land was also prone to invasion in the lower-elevation parts of the study area. Pine species (initially *P. pinaster* but later also *P. radiata*) invaded the higher slopes, spreading from small plantations within the study area, and through long-distance dispersal of seeds from plantations on adjacent farms. Fires also influenced these invasions. Three large fires in the study area since the 1950s would have resulted in the release and dispersal of large numbers of seeds from pines and hakeas, and

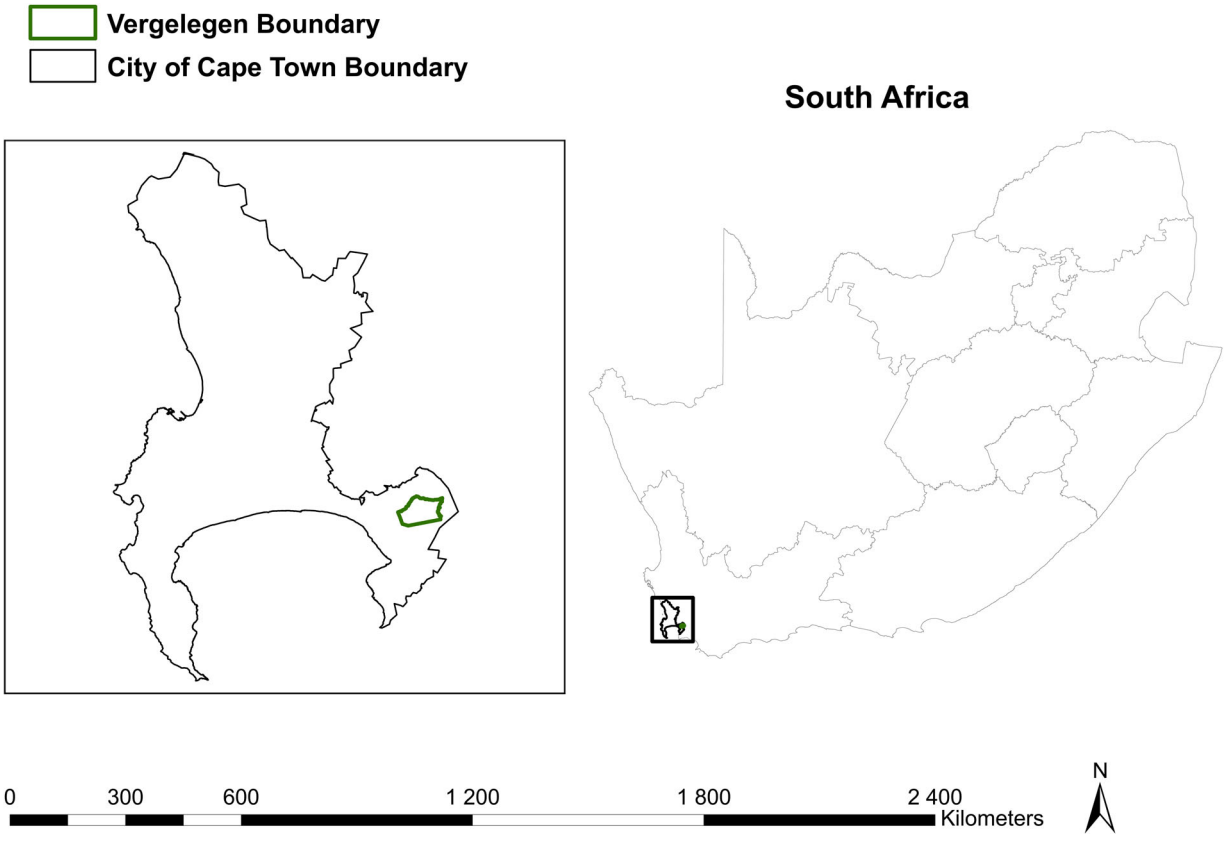

Figure 1. The study area at Vergelegen within the boundary of the City of Cape Town in the Western Cape Province, South Africa.

Figure 2. Invasive alien plants (IAPs) on Vergelegen and some of the approaches used to manage them: (a) General view of the extent of IAPs (dark areas) on Vergelegen in 2006; (b) mountain slopes covered by burnt stands of pines (mainly *Pinus pinaster*); (c) contracting team clearing a dense *Pinus pinaster* stand; (d) area cleared of *Pinus pinaster* by the Razorback; (e) dense stand of *Eucalyptus* species; (f) dense stand of wattles (mainly *Acacia mearnsii*); (g) Razorback clearing a dense stand of alien plants; (h) stacks of biomass created by the clearing programme; (i) prescribed burning to remove biomass.

would have stimulated mass germination of soil-stored wattle seeds, resulting in the invasion of large tracts of natural fynbos vegetation (Richardson & Brown, 1986; Richardson & Cowling, 1992; Richardson & Higgins 1998; Rouget *et al.*, 2001; Richardson & Kluge, 2008).

Since the purchase of Vergelegen by Anglo American in 1987, there has been a strong focus on producing world-class wines and managing the natural environment as well as the farm's cultural heritage (http://www.vergelegen.co.za/heritage.html). A major part of the investment in the conservation of the natural environment at Vergelegen has been directed towards clearing IAPs, restoring natural vegetation and conserving biodiversity in the 2200 ha of non-agricultural land on the estate (Table 1).

History of control efforts

The history of alien plant control on Vergelegen between 2004 and 2015 was reconstructed by reviewing monthly management reports from Vergelegen environmental project managers, the minutes of meetings of Vergelegen environmental managers and reports from several independent consultants who developed the alien plant control management plan and subsequent audit reports. This information was used to set out a historical synopsis of the key stages of the clearing operations.

Measuring control effectiveness

Changes in alien plant density over time

The change in alien plant cover between 2004 and 2015 was estimated in order to assess the effectiveness of the control programme. Six categories of alien tree canopy cover were used in the 2002 management plan: occasional (<1% cover); very scattered (1–5% cover); scattered (5–25% cover); medium (25–50% cover); dense (50–75% cover); and closed (>75% cover). The 2002 plan used roads and contours to divide the area into 26 management units based on the workload (estimated time and funding required to clear the invasive trees in that unit) (Figure 3).

The density of invasive trees and shrubs in 2015 was estimated from March 2015 aerial imagery obtained from the City of Cape Town. The density of invasive trees was noted for each management unit for comparison with 2002 estimates.

Management progress

The original alien control management plan established three main clearing phases:

Table 1. A summary of key events during operations aimed at clearing invasive alien plants (IAPs) at Vergelegen between 1997 and 2015.

Date	Event	Reason for event	Outcome and significance
1997	Working for Water cleared 230 ha of the mountainous area	Details on who implemented and paid for this event were not recorded	Unknown
1997	Survey of invasive alien plant density (Consultant A)	Intended to provide input for deciding on priorities and methods for management	Recommendations were not implemented
2002	Management plan (including cost estimations and prioritisation) drawn up by a consultant (Consultant B)	After the 1997 fire the intensity of the fire and the re-growth of invasive alien plants (IAPs) after the fire forced Vergelegen to look at options to reduce the impacts associated with IAPs	The estate was divided into 26 management units (MUs). Provided the goals of the management plan
2004	Appointment of a project manager to oversee implementation of plan	Experienced project manager was required to oversee the project implementation	Start of the implementation of the management plan
2004–2009	Appointment of local woodcutting team of six people	Local wood cutting was appointed to promote local community business growth and job creation	Local woodcutter and her team were trained by the estate in the use of chainsaws and herbicides. This team was used for alien clearing on the property
2005–2006	Use of Razorback – a tracked machine in this case a bulldozer with mover and mulcher in front of the machine, the Razorback would drive into dense IAP stands, cut and mulch the material, leaving it broadcasted over the cleared site.	Need for feasible way to control plants and biomass effectively	Mechanical clearing of accessible areas
2006	Appointment of a consultant (Consultant C) to audit implementation of management plan	To audit work completed between 2004 and 2006	Identification of inconsistencies and deviation from best practice. Recommendation that MUs should be contracted out to contractors to supplement the in-house team
2006–2009	Increased clearing team numbers from 6 to 40	To increase speed of clearing operation	Problems encountered – needed to clear steep areas; accumulation of biomass; needed to burn outside of ecologically optimum season
2009	Large wildfire	Unplanned event	Large area burnt, including 1027 ha that had been cleared
2009	Appointment of Consultant C to assess implications of fire	Audit work completed before the fire and assessed impacts of fire on the clearing programme	Needed to shift priorities
2009	New management plan drawn up in response to perceived need to shift priorities	To provide a new approach to the project and to help deal with IAP regrowth after the 2009 fire	Provided the goals of the management plan
2010	New project manager appointed; additional contracting teams appointed	To assist with project implementation	Two new teams and project manager was assigned to the insurance project (all areas cleared before the 2009 fire)
2011	Three additional contracting teams appointed	To increase the speed of initial clearing and assist with follow-up	Contractor numbers significantly increased from 60 to over 200 workers to increase the speed of the initial clearing operation
2012	Funding for initial clearing funding curtailed	Initial clearing funding was stopped	Further initial clearing was stopped and available funds were allocated to follow-up operations
2013–2015	Project priority shift	The increase in contracting teams increased the speed of the clearing operation but also increased the biomass and the size of areas requiring annual follow-up	Work prioritisation shifted to follow-up and biomass removal

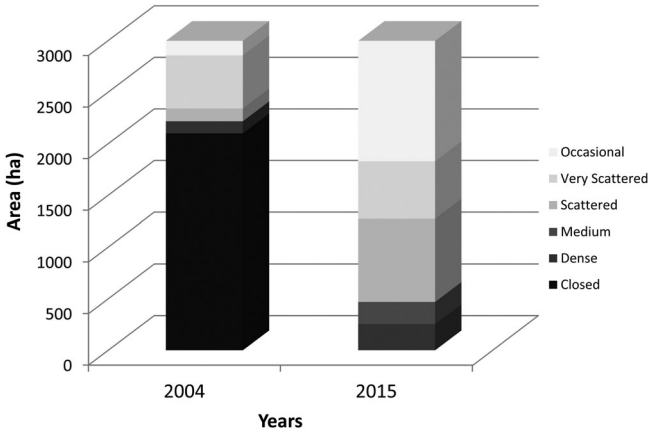

Figure 3. Area occupied by invasive alien plants in six cover classes at Vergelegen in 2004 and 2015. The classes are occasional (<1% cover); very scattered (1–5% cover); scattered (5–25% cover); medium (25–50% cover); dense (50–75% cover); and closed (>75% cover).

1. Initial clearing: Felling of all invasive trees and, in some cases, removal of all felled biomass.
2. Follow-up: Follow-up clearing once every 1.5 to 2 years to remove any plants that may have been missed in the initial operation and any seedlings/saplings.
3. Maintenance control: Ongoing removal of emergent IAPs from an alien plant population that has been reduced to a level that can be contained at a relatively low cost in perpetuity.

However, based on the experience gained and the site-specific issues that came to light, the management plan was adjusted in 2013 to include nine management phases (Table 2). This made no difference to the annual work already set out by the management plan; it merely allowed for five follow-up treatments (1 treatment per year), and a maintenance phase, and provided a logical flow to monitor the alien plant control programme progress. We established the progress within each management phase for each of the years that the project was active, starting before clearing operations in 2004 up to and including the 2015 operations. The progress as originally planned in 2004 was then compared to the actual project flow between 2004 and 2015.

Estimating the cost of clearing

We obtained the annual budgeted costs for clearing and follow-up from the 2002 management plan and compared these estimates to the actual expenditures from monthly project costing reports. These reports detailed the actual amounts spent on clearing, follow-up, management, equipment and other associated costs. All costs were inflated to 2015 values using the annual consumer price index to compare the differences in cost between the budget as set out in the original management plan in 2002 and the actual costs incurred.

Comparison of planned and actual costs

We determined a cost variance ratio between the planned and actual costs for the alien control programme. The cost variance ratio (CVR) was determined as $CVR = \frac{(Actuals\ Cost - Planned\ Cost)}{Planned\ Cost}$ for each of the 26 management units (MUs). The MUs were further divided into three categories based on their accessibility and difficulty in terms of conducting management operations: easy, moderate or difficult. "Easy access" included MUs that were surrounded by roads, in and around agricultural areas, old agricultural lands and old plantations. "Moderate access" MUs were those where at least one side of the area was accessible by road. "Difficult" MUs were those with no road access where at least 15 minutes of walking was required to reach work sites; these occurred at higher elevations and most were on steep and/or rocky terrain. The CVR was used to determine

Table 2. Nine management phases of the alien plant control programme implemented on Vergelegen Wine Estate.

Phase	Management phase	Description of management phase
1	Treatment not yet initiated	No management action taken. This includes areas where initial clearing has not taken place yet, agricultural and hospitality areas.
2	Initial clearing	Initial clearing is the initial control action that drastically decreases the existing alien plant population. The preferred treatment was cut stump where stems are cut as low as practical. Herbicides are applied as recommended for the specific species being treated.
3	Biomass treatment	Biomass removal is a critical part of the alien control programme. There are various methods to remove biomass created by clearing alien plants in fynbos, however prescribed burning was the most effective and practical means of controlling biomass created by the Vergelegen alien control programme. This stage includes areas within the clearing project that are located on higher slopes. Biomass was not removed in these areas due to the risk of run-away fires. Follow-up is still taking place annually, with increasing costs.
4 5 6 7 8	Follow-up 1 Follow-up 2 Follow-up 3 Follow-up 4 Follow-up 5	Follow-up is the control of seedling, root suckers and coppice growth that occurs after initial clearing. WfW has a policy of three follow-ups before they hand over the treated area to the relevant land owner. However on the Vergelegen project we worked on five follow-up treatments since new alien plant seeds were introduced from the surrounding invaded area.
9	Maintenance phase	Maintenance phases include areas that have less than 5% invasion present annually, these areas require minimal resources to control plant invasion.

whether the variance between planned and actual cost increased with the increase in difficulty of access. To test whether there was an impact of the difficulty of control at a location on the cost variance, cost variance estimates were recalculated as log (1+the cost variance estimate) in an effort to normalise the data. An analysis of variance (ANOVA) was used to look at the impact of access on the cost variance, with Tukey's post hoc test used to look for differences between any of the treatments.

RESULTS

History of control efforts

A survey of alien vegetation density was conducted in 1997 by a consultant ("Consultant A") after a fire burnt the area in 1997. The fire was considered to be difficult to control due to the large fuel build-up that had occurred as a result of the dense cover of IAPs. The purpose of this survey was to assess the density of IAPs in the burned areas, with a view to prioritising areas for clearing, identifying suitable removal methods and designing management strategies. The plan suggested that management should be initiated as soon as possible to prevent the areas from becoming a solid forest of IAPs over the next 20 years ("Consultant A"). The implementation of this plan was delayed by 5 years due to a lack of funding.

During a series of meetings with City of Cape Town reserve managers and consultants who urged Vergelegen to take action in 2002, the impacts of IAPs were reconsidered by the Vergelegen board members, and a follow-up management plan was drawn up by a consultant ("Consultant B"). This plan included a complete estimation of costs and an area prioritisation plan. The estate was mapped and divided into 26 management units (MUs) using distinct land marks as boundaries. Funding was made available in 2004 and a project manager ("Project manager A") was appointed. The first management efforts on the estate focused on areas with lower densities of IAPs and areas earmarked for the creation of fire breaks. This was done by appointing a local woodcutting contractor who had been working on the estate harvesting firewood. Her team of six people was trained to use chainsaws and herbicides for the control of IAPs and also in how to conduct prescribed burning.

Besides the contracting team that cleared IAPs, a Razerback machine (Figure 2) was used to clear IAPs in easily accessible areas. The Razorback is a heavy machine which is driven into and against the material to be cut. The material is cut while the machine is moving forwards and is pulverised by the heavy and sharp cutters (e.g. a 4 m tall pine tree can be shredded in 37 s, leaving only a stump remaining). The mulch produced by this machine does not create a large fire hazard as it decomposes rapidly, resulting in good recovery of the natural vegetation. The unit was unfortunately only available during wet winters and, although successful, was not used extensively due to very heavy winter precipitation and also the high costs involved.

In 2006, as part of Vergelegen's quality control requirements, an independent consultant ("Consultant C") was appointed to audit the implementation of the 2002 management plan to assess compliance and effectiveness. Consultant C's report provided an independent assessment of whether the approved funding had been spent correctly. Seven site inspections were done and on-site meetings were conducted with project manager A. Key findings of the audit were that the original plan had no clear site-prioritisation specifications, e.g. that lower-elevation areas, and light-to-medium density stands should be prioritised over dense stands. The audit recommended that expenditure on each MU (or part of an MU) should be noted and accounted for separately to ensure the accumulation of costing knowledge for each MU to allow for an informed system of budgeting.

The audit also reported a failure to adhere to the schedule of follow-up after initial clearing. There were 2–3 year gaps between initial clearing and follow-up treatments, while the plan called for follow-ups in the first growing season following the clearing (Consultant C, Audit report, 2006). The audit also found very poor compliance with the original management plan drawn up by Consultant B. However, according to project manager A, the non-compliance was intentional as the original plan was never considered in the work schedule and work priorities were rethought and applied based on the local knowledge of project managers. The audit pointed out that even though the project manager did not follow the 2002 management plan, some success was achieved in the clearing of important fire breaks, the "testing" of the Razorback, and outsourcing of the clearing activities to local entrepreneurs including the provision of training, skills transfer and the acquisition of equipment. The sale of timber to offset the cost of clearing also contributed to offsetting the project costs.

Between 2006 and 2009, the project team was increased to 40 people, comprising 12 chainsaw operators and 28 workers who focussed on stacking and follow-up. As the work progressed to the higher and steeper slopes, the workforce had to contend with greater amounts of burnt vegetation from the 1997 fire. This slowed the clearing and follow-up processes. Biomass was reduced by conducting stack and block burns, but burning was only conducted in winter because of the risk of run-away fires at other times of the year. Other forms of biomass removal included the harvesting of wattle and eucalypt wood for firewood, and viable pine timber was sold to saw mills. Approximately 1027 ha of invaded land was cleared between 2006 and 2009.

In February and March of 2009 another large fire swept across the Helderberg Basin, including the 1027 ha of Vergelegen that had been cleared in preceding years. This event precipitated the need to revisit the management plan to prioritise follow-up weeding in areas burnt in the fire. To advise on the alteration of the management plan, consultant C was appointed to adjust the management plan to accommodate the unplanned wildfire. The post-fire assessment indicated that the project focus needed to shift to areas cleared before the fire since the fire had triggered mass germination of soil-stored seeds.

The follow-up areas were prioritised as follows:

- Areas immediately around buildings and other infrastructure, to avoid regrowth that would constitute a fire hazard in future;
- Areas identified as asset protection zones;
- Areas of low-density invasions, where the returns on investment would be much higher (Higgins *et al*., 2000);
- Areas that could provide access for security reasons, or to initial clearing sites;
- The tops of slopes, watercourses, and steep, long bare slopes, to inhibit the spread of seeds downhill or downstream, where they would invade new areas; and
- Disturbed sites, to remove seedlings that had emerged as a result of mass germination of the soil-stored seeds of wattles.

In 2009, a second project manager ("Project manager B") was appointed to focus on all the areas cleared before the 2009 fire, and additional funding was made available after a successful insurance claim. Two new contracting teams were appointed, each comprising 10 workers.

In 2011, Vergelegen management appointed additional teams to speed up the initial clearing programme. An area of 446 ha was to be cleared, most of it on the higher slopes that supported a dense cover of pines with a mixture of wattles and eucalypts along drainage lines.

Vergelegen is owned by Anglo American who are primarily a mining company operating in a volatile social and financial environment. In 2012 the decision was made to temporarily stop all initial clearing after Anglo American experienced financial constraints following a series of strikes in the mining industry. The focus of the project shifted towards follow-up treatments in already cleared areas and to biomass removal.

Changes in alien plant density over time

The control operations were successful in achieving large reductions in the cover of IAPs over the study period (Figure 3). In 2004, 70% of the area was covered by alien plants in the closed cover category, but this was reduced to 0% by 2015. The area covered by alien plants in the dense and medium cover categories increased from 4 to 9%, and from 0 to 7%, respectively by 2015. Alien plants in the scattered, very scattered and occasional cover categories increased from 4 to 27%, 17 to 19% and 5 to 39% by 2015, respectively. Between 2004 and 2015, the overall extent of closed-cover stands of IAPs decreased by 70%, 16% of which changed to occasional cover, 26% to very scattered cover, 38% to scattered cover, 7% to medium cover and 12% to dense cover. The area covered by alien plants in the dense category in 2004 had decreased to either medium or occasional cover by 2015, in about equal proportions. The lack of significant change from dense to medium cover can be attributed to the presence of biomass created by the clearing operations which made follow-up treatment time-consuming, costly and in many cases ineffective. The lower density classifications including occasional (38%), very scattered (18%) and scattered (26%) increased significantly between 2004 and 2015. The remaining dense (9%) areas were those where initial clearing had not yet been initiated.

Management progress

The clearing operations did not proceed according to the original management plan, which proposed a starting date of 2003 and called for completion of operations by 2013 (Figure 4A). The original plan estimated that 72% of the

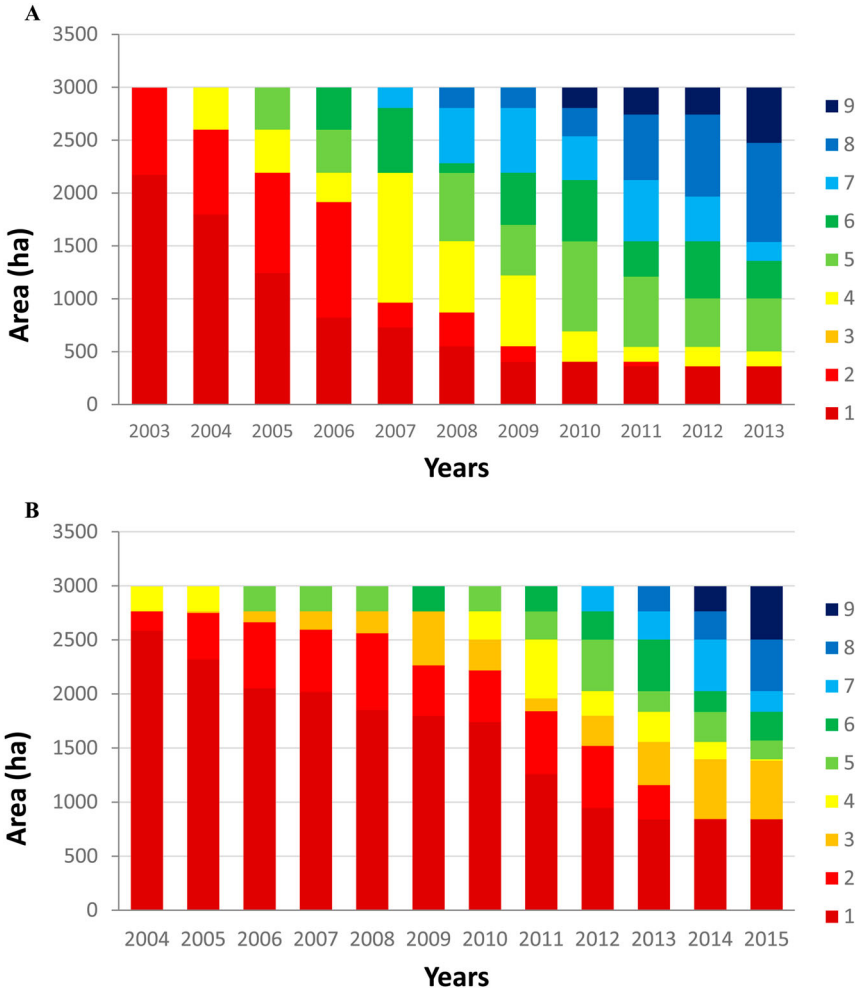

Figure 4. The planned and actual project flow through nine implemented management phases over 12 years (see Table 2 for phases). (A) The planned project flow from 2003 to 2013. (B) The actual management phases achieved between 2004 and 2015.

initial clearing should have been completed by 2006, but only 23% of the area had been cleared at this time. The numbers of follow-up treatments required for each of the MUs were inconsistent, and ranged from one to five. Based on the original plan, areas that had a medium to closed cover of pine species were allocated one to three follow-ups whereas areas invaded by wattles were allocated five follow-ups. Biomass removal was not included as a management phase in the original 2002 management plan, and no consideration was given to ways of dealing with the large volume of dead biomass that was created by initial clearing operations.

The project was continued in 2004 after additional funding was made available (Figure 4). Between 2004 and 2009, an additional area of ~1000 ha was cleared, but only 500 ha of this received one follow-up treatment between 2006 and 2009. In addition to alien plant control operations funded by Vergelegen, a relatively small area (230 ha) was cleared and followed up by WfW up to and including 1997. This work focused on high altitude areas on the boundary of the property. A large wildfire burnt the cleared areas in 1997 and WfW teams did not return to Vergelegen. Information regarding the cost and time spent on Vergelegen by WfW is not available, as the work was carried out on an ad hoc and unplanned basis.

After the 2009 fire additional teams were appointed to work solely on follow-up, which allowed all cleared areas to receive one follow-up treatment per year. In 2011 the rate of initial clearing increased after additional teams were appointed. The last initial clearing efforts stopped in 2012, when funding for the project was terminated. However, to prevent the cleared areas from becoming reinvaded, follow-up and biomass reduction treatments were continued. No work has thus been carried out on approximately 180 ha that was proposed for clearing in the 2002 management plan.

Estimated cost of clearing

The 2002 management plan estimated the combined cost of clearing and follow-up to be ZAR 12.19 million over the next 12 years (ZAR 6 million was budgeted for initial clearing with an average cost of ZAR 2332 ha^{-1}, and ZAR 6.19 million was budgeted for follow-up treatments). The annual costs were estimated at ZAR 1.3 million in 2003, reducing to ZAR 180 000 in 2013 (Figure 5A).

In reality, the original plan was not rigorously followed, and the cost of control was much higher than planned. Between 2004 and 2009 funds were allocated mainly to initial clearing, with very little going to planned follow-up operations (Figure 5B). After the 2009 fire, follow-up treatments were given priority, with the remaining funds going to further initial clearing. The actual amount spent on initial clearing between 2004 and 2015 was ZAR 26.4 million (more than four times the budgeted amount) with an average of ZAR 13 241 ha^{-1}. The actual amount spent on follow-up was ZAR 17.2 million (three times the budgeted amount) (Figure 6).

Variance between budgeted and actual costs

The difficulty of control in a management unit did not affect the cost variance estimate (F 2,19=1.44, p=0.26) and no pairwise comparisons were significant after Tukey's post hoc test (at p=0.05).

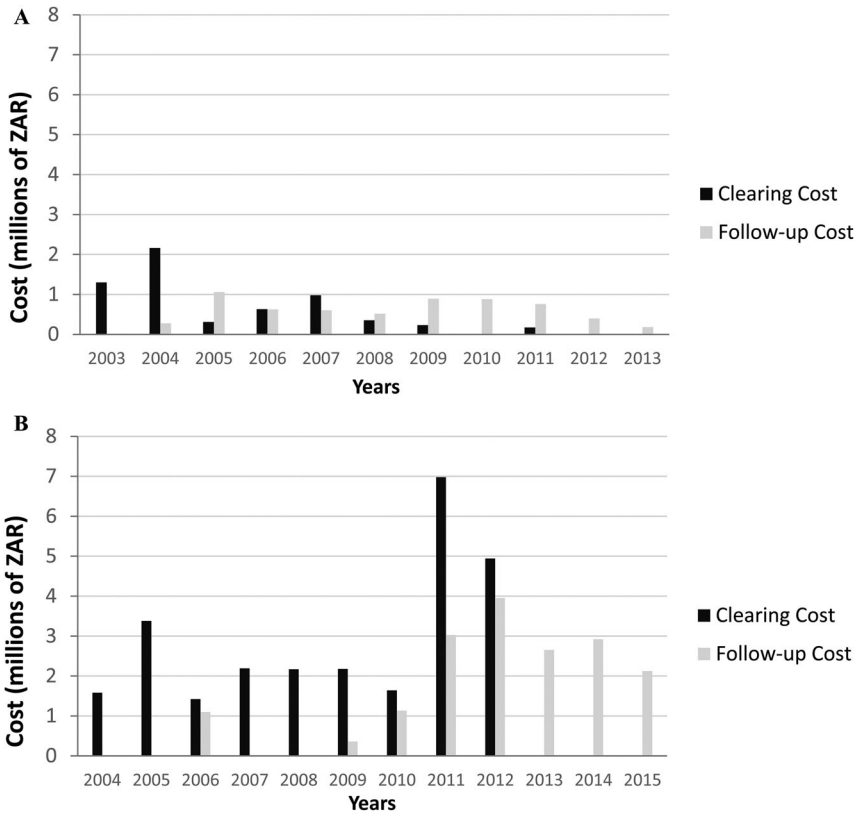

Figure 5. Actual annual project costs compared to budgeted costs in ZAR (South African Rand). (A) The budgeted costs per year between 2003 and 2013. (B) The actual amount spent per year for initial clearing and follow-up between 2004 and 2015.

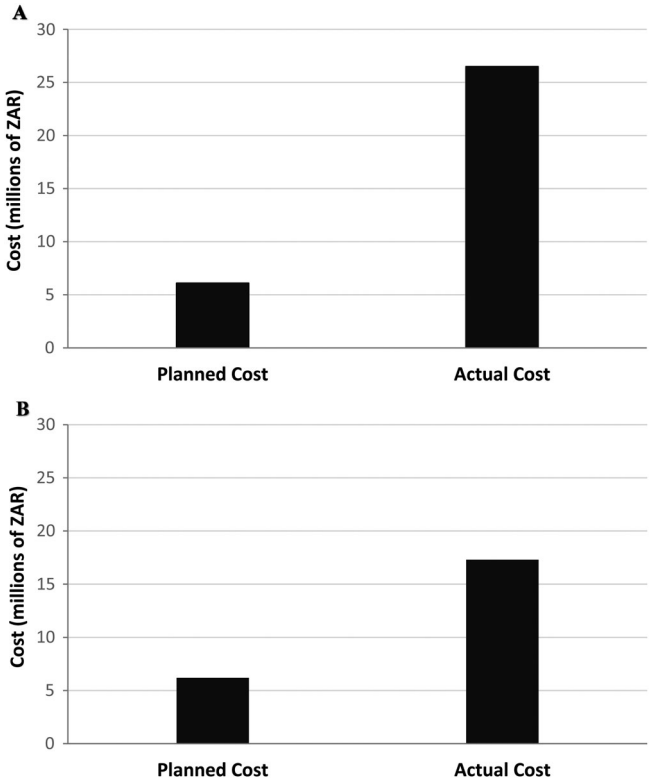

Figure 6. Total planned and actual costs spent on initial clearing of invasive alien plants and follow-up operations at Vergelegen. (A) The planned costs for initial clearing between 2003 and 2013 versus the actual costs of clearing between 2004 and 2015. (B) Planned costs for follow-up in the original management plan versus the actual cost for follow-up between 2004 and 2015.

DISCUSSION

Attempts to reduce the extent of invasion by IAPs on Vergelegen Estate have achieved some success. Dense invasions have been reduced from 73 to 8% of the area, but the cost was much greater than was originally envisaged and populations of IAPs remain, albeit at much lower densities than at the start of operations. Should the funding for the operation be terminated, or even reduced, the substantial gains achieved to date will be lost and the area will return to its former heavily-invaded state (van Wilgen *et al.*, 2016, b; Fill *et al.*, 2017). The experience at Vergelegen has clearly demonstrated the complex nature of the environment in which IAP control projects have to operate, a feature that characterises similar projects elsewhere (Roura-Pascual *et al.*, 2009; Woodford *et al.*, 2016). In this sense, the problems that confront private landowners are not substantially different from those faced by projects implemented by WfW on public land in the CFR. Key problems include the lack of foundational knowledge on which to base estimates of the cost of achieving long-term goals; the lack of effective methods to control IAPs; the fluctuating nature of funding due to competing demands for scarce resources; the occurrence of unplanned events, especially wildfires; and unforeseen complications, such as the generation of large amounts of woody biomass. Even with access to substantial funding, the state has only been able to reach a small proportion of all invaded land under its control in the CFR (van Wilgen *et al.*, 2012), and the goal of achieving sustainable control may require a focus on priority areas, leaving others unmanaged (van Wilgen *et al.*, 2016a). One feature of the Vergelegen case that separates it from similar operations in the region is the existence of a formal management plan, and a commitment to auditing the plan, which has been absent from state-funded control operations in the CFR to date (van Wilgen *et al.*, 2012b).

The private landowner at Vergelegen, Anglo-American, is a large corporation with access to substantial financial reserves. This corporation has a stated commitment to managing the natural environment and cultural heritage of the estate. The same is not true for many other private landowners. This begs the question of whether most private landowners will ever be in a position to make effective contributions to gaining control of IAPs at the landscape scale in the CFR, as they are expected and are legally obliged to do in terms of regulations under the National Environmental Management: Biodiversity Act (Act 10 of 2004). The government has sought to address this challenge by introducing "landuser incentives" to provide support to landowners to pay for the labour required for the initial clearing and follow-up operations. Under this arrangement, landowners provide additional resources, and commit to preventing re-invasion of cleared areas. However, the goal of this assistance (to extend the control of IAPs beyond the state-owned areas, thus gaining control over much larger areas) may not be realised, for all of the reasons outlined above, and especially because the funds available for such incentives are limited. It is clear that additional sources of reliable funding are needed to address these problems on a wide scale on private land in the CFR. One possible solution would be to implement a system of payment for ecosystem services (PES), in which off-site users of services (e.g. water) are charged a levy which could be used to support control projects in areas that generate the services (Blignaut *et al.*, 2007). If the goal of achieving control of IAPs on privately-owned land is to be achieved, it is imperative to agree upon, and to implement, such PES programmes.

ACKNOWLEDGEMENTS

We are grateful to Vergelegen Wine Estate for supporting this research. BvW and DMR acknowledge funding from the DST-NRF Centre of Excellence for Invasion Biology and the National Research Foundation (grants 85417 to DMR and 87550 to BWvW). John Wilson provided advice on statistical analyses.

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